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Yoshida

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(54) **RADIO-FREQUENCY MODULE AND COMMUNICATION DEVICE**

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H04B 1/44	(2006.01)
H04B 1/00	(2006.01)
H04B 1/04	(2006.01)

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(58) **Field of Classification Search**
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See application file for complete search history.

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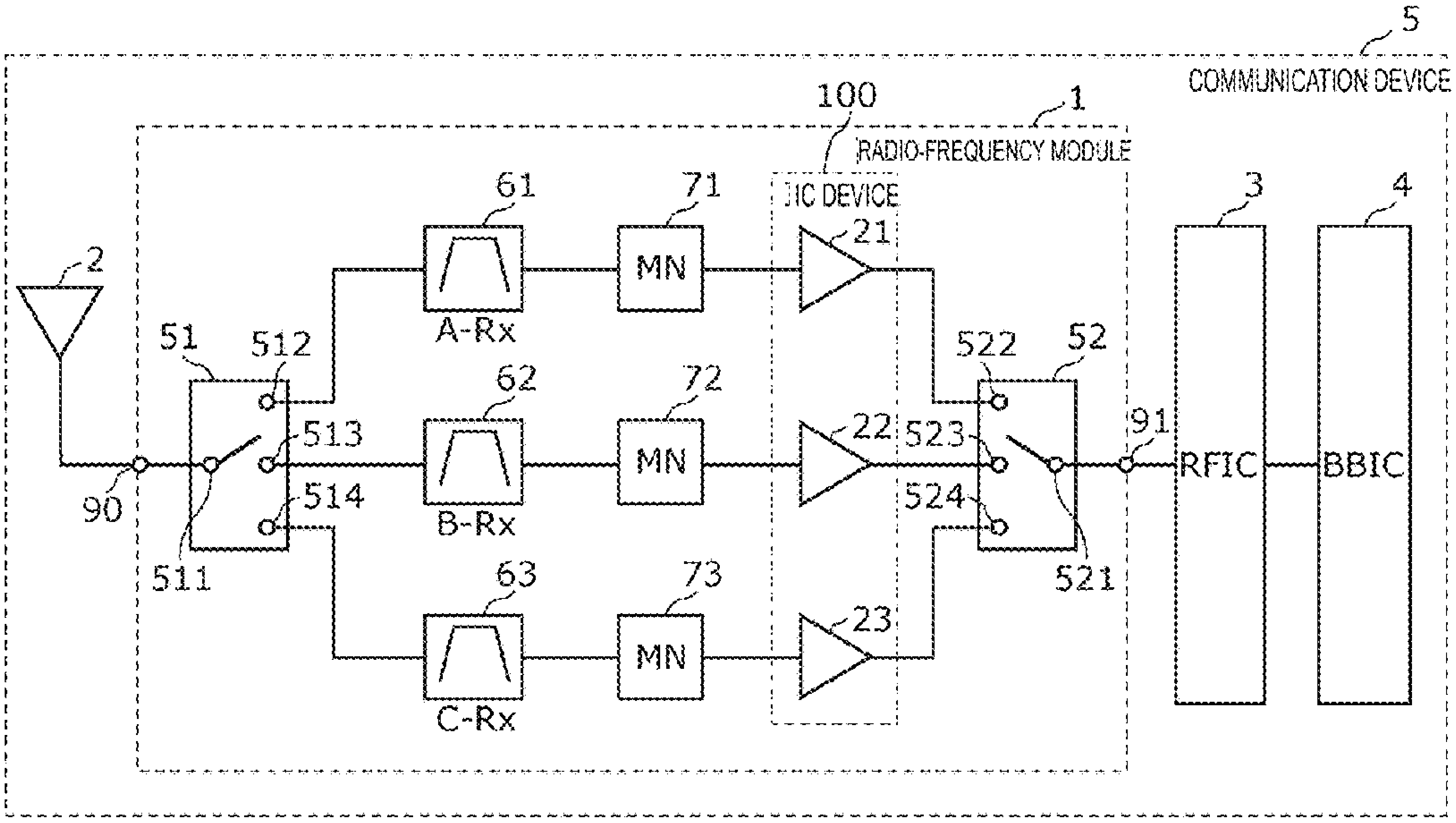
(57) **ABSTRACT**

A radio-frequency module includes an integrated circuit (IC) device and an external inductor provided outside the IC device. The IC device includes a plurality of low-noise amplifiers, one or more inductors, and a switching circuit. The plurality of low-noise amplifiers includes a plurality of transistors in one to one correspondence. The one or more inductors are coupled to one or more of the plurality of transistors. Each inductor is coupled to the emitter or source of a corresponding one of the plurality of transistors. The switching circuit is coupled between the emitter or source of each of the plurality of transistors and the external inductor. The external inductor is coupled between the switching circuit and ground in series with each of the one or more inductors via the switching circuit.

20 Claims, 4 Drawing Sheets



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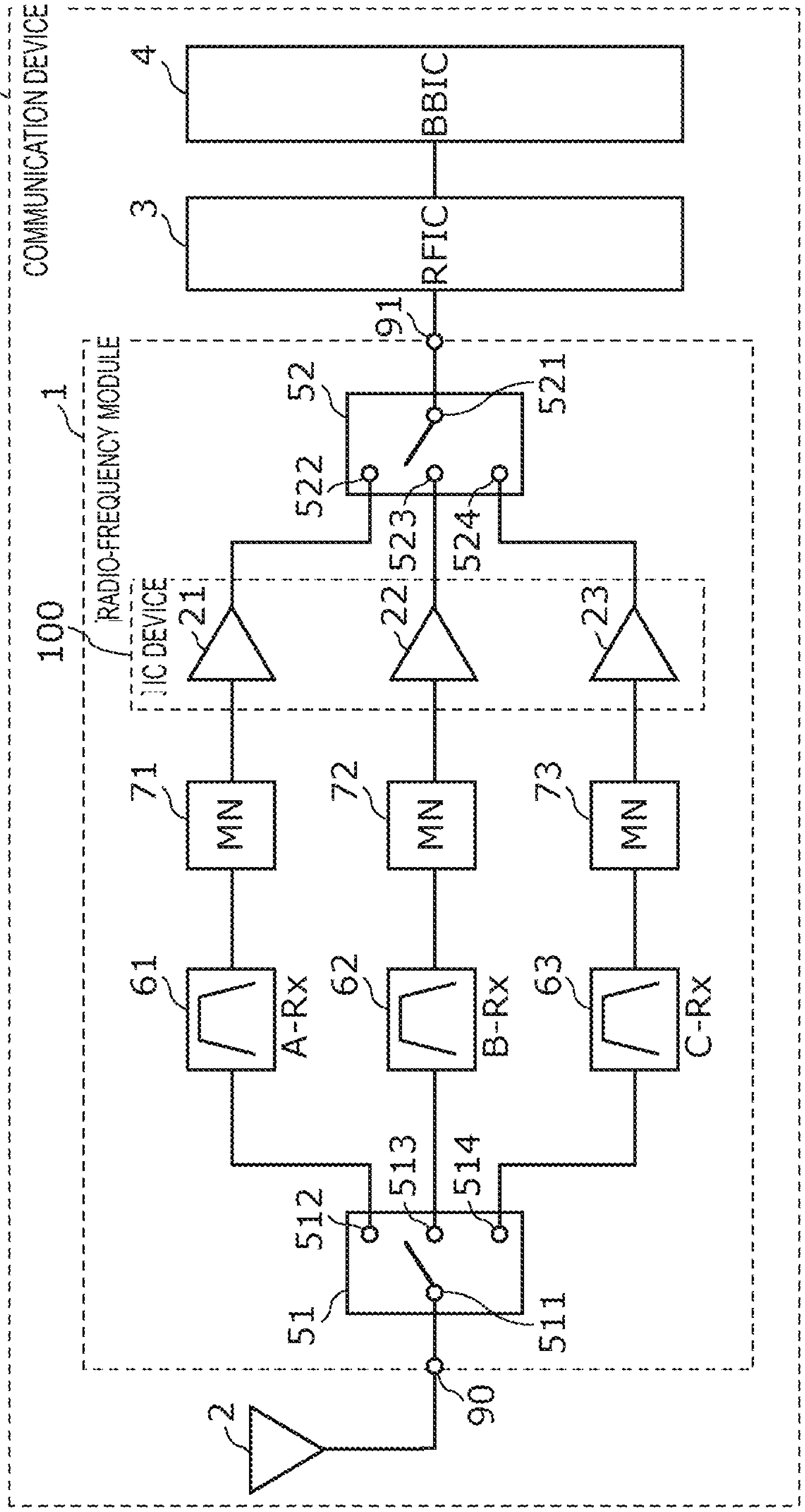

5
COMMUNICATION DEVICE
4
BBIC
3
RFIC
91
52
521
522
523
524
1
RADIO-FREQUENCY MODULE
100
IC DEVICE
21
22
23
71
72
73
MN
MN
MN
61
62
63
A-Rx
B-Rx
C-Rx
51
511
512
513
514
90
2

FIG.1

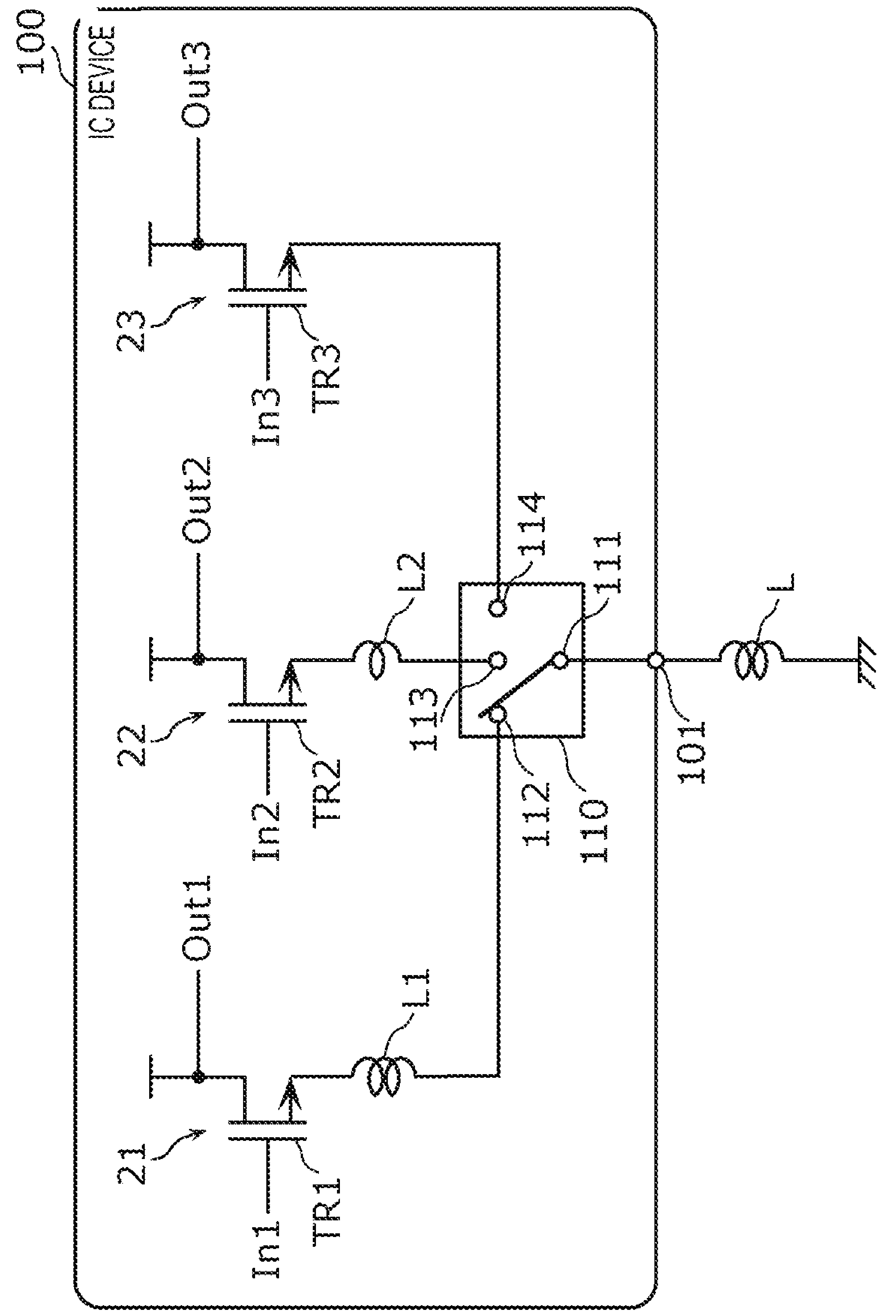

100
IC DEVICE
Out3
23
TR3
In3
Out2
22
TR2
In2
L2
114
113
111
112
110
101
L
Out1
21
TR1
In1
L1

FIG. 2

FIG. 3

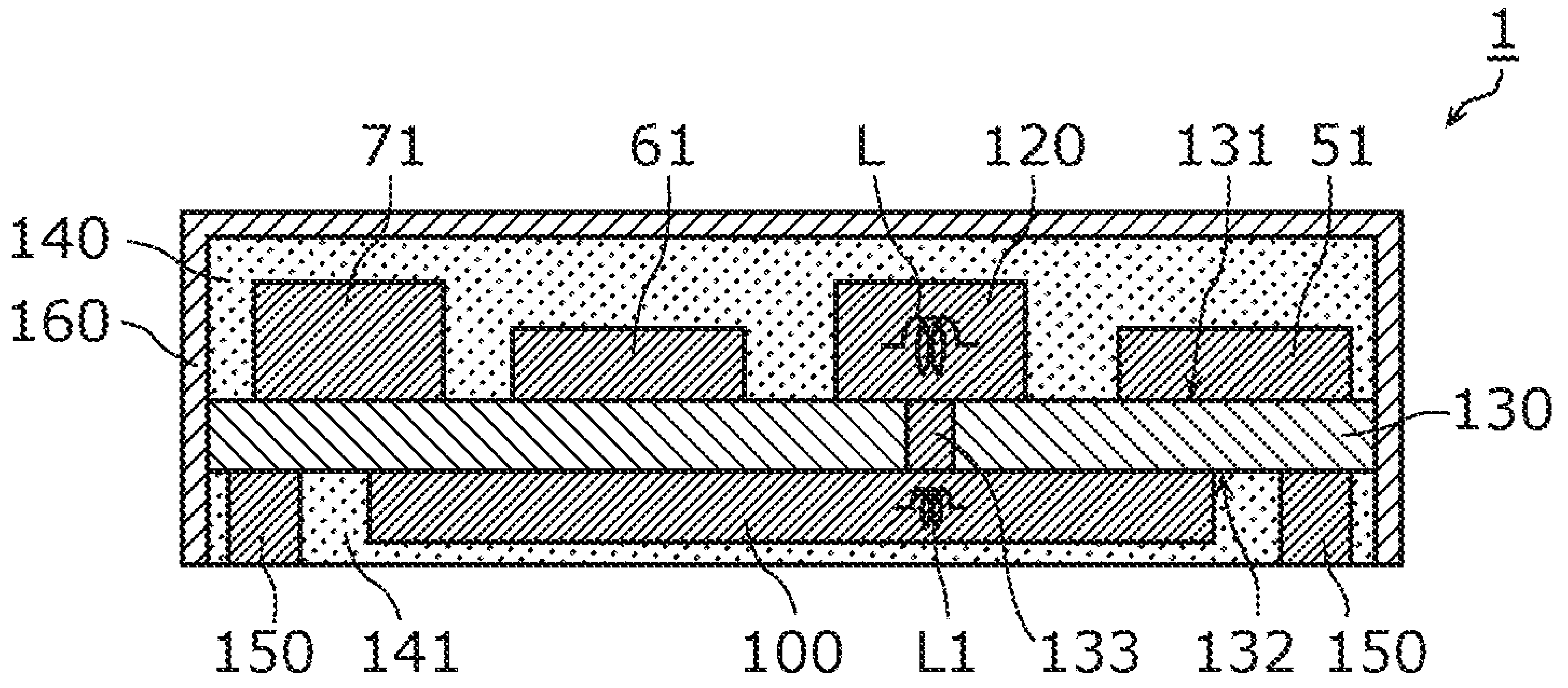


FIG. 4

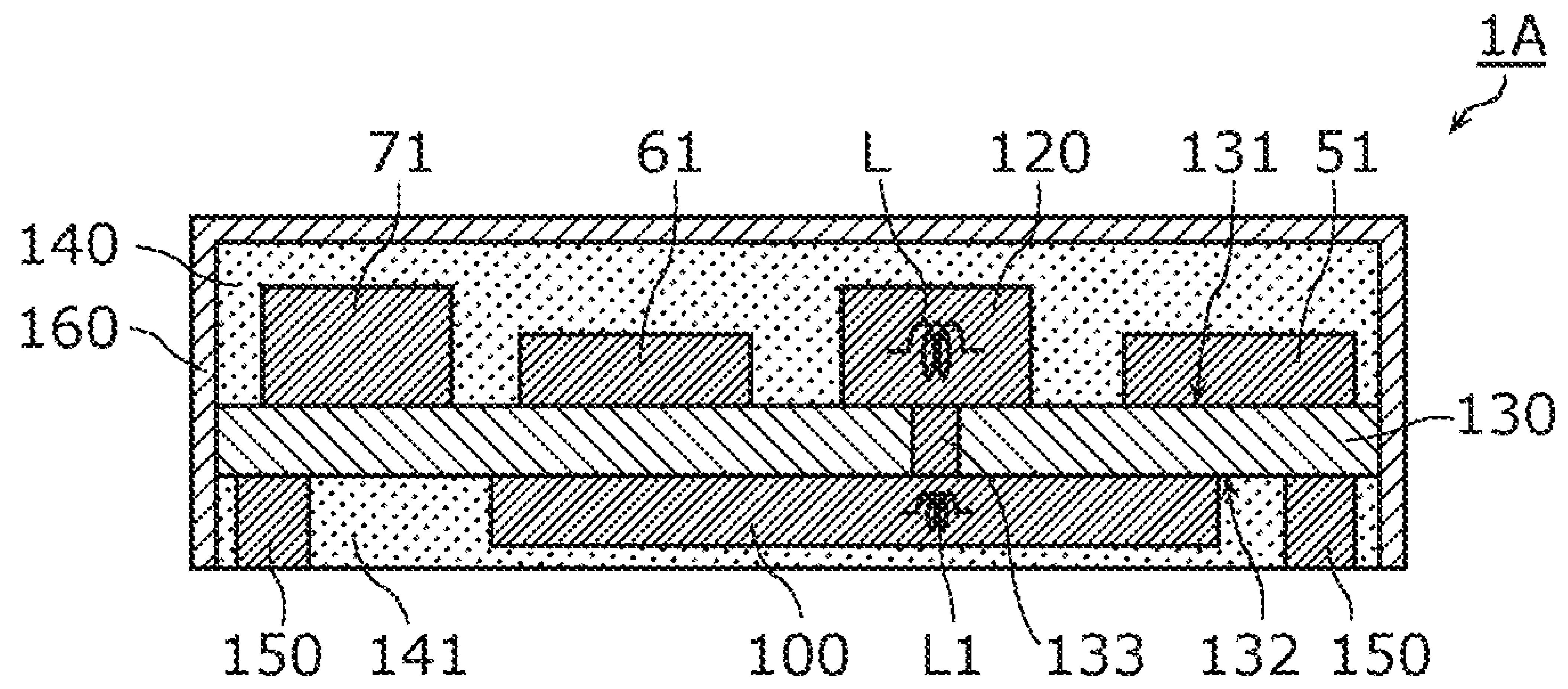


FIG. 5

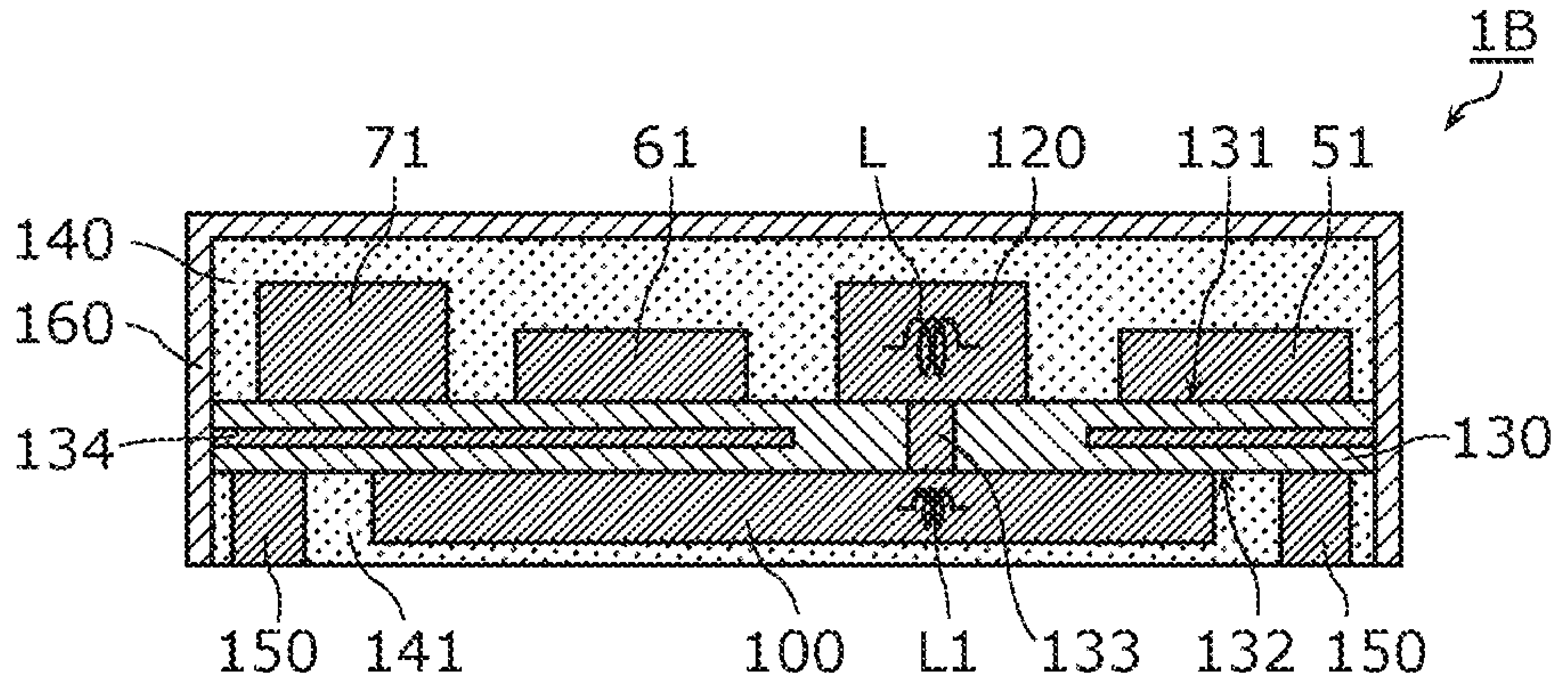
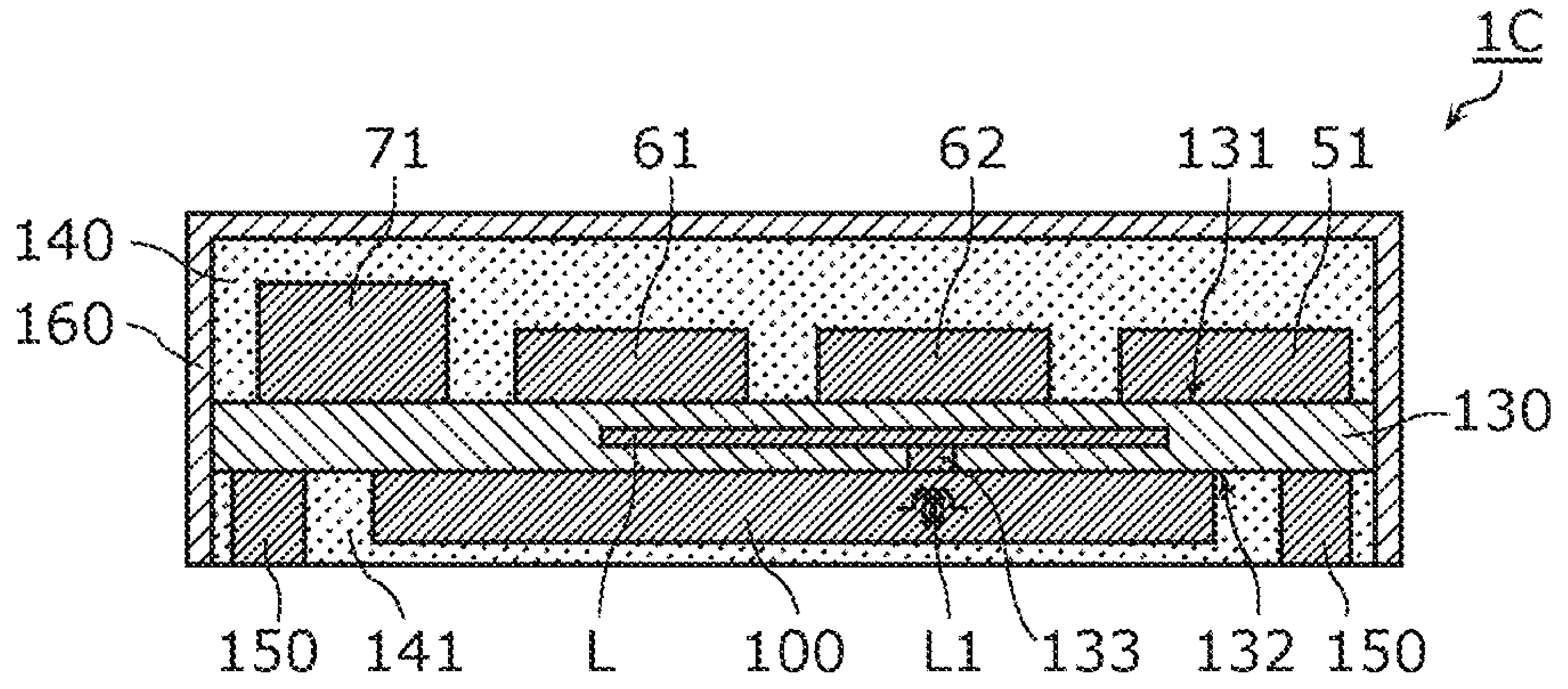


FIG. 6



RADIO-FREQUENCY MODULE AND COMMUNICATION DEVICE

CROSS-REFERENCE TO RELATED APPLICATION

The present application claims priority to Japanese patent application JP2020-113420, filed Jun. 30, 2020, the entire contents of which being incorporated herein by reference.

BACKGROUND

1. Field

The present disclosure relates to a radio-frequency module and a communication device.

2. Description of the Related Art

Japanese Unexamined Patent Application Publication No. 10-126174 (Patent Document 1) discloses an integrated circuit operable as a low-noise amplifier that is formed by integrating an amplifier transistor and an inductor coupled to the source or emitter of the amplifier transistor. The inductor in the integrated circuit disclosed in Patent Document 1 is formed by using a metal wire.

SUMMARY

When an inductor is formed by using a metal wire in an integrated circuit as the known technology described above, the size of the integrated circuit increases because a space larger than a given size is needed. When multiple low-noise amplifiers are integrated together, in addition to spaces for amplifier transistors, spaces for inductors are also needed, and as a result, the size of the integrated circuit further increases. Moreover, since the inductor coupled to the source or emitter of the amplifier transistor largely affects characteristics of the low-noise amplifier, there is a need for a low-loss inductor.

Accordingly, the present disclosure provides a small radio-frequency module and a small communication device that include a plurality of low-noise amplifiers with improved characteristics.

A radio-frequency module according to an aspect of the present disclosure includes an integrated circuit (IC) device and an external inductor provided outside the IC device. The IC device includes a plurality of low-noise amplifiers including a plurality of amplifier transistors in one to one correspondence, one or more inductors coupled to one or more of the plurality of amplifier transistors, each inductor being coupled to the emitter or source of a corresponding one of the plurality of amplifier transistors, and a switching circuit coupled between the emitter or source of each of the plurality of amplifier transistors and the external inductor, and the external inductor is coupled between the switching circuit and ground in series with each of the one or more inductors via the switching circuit.

A communication device according to an aspect of the present disclosure includes a signal processing circuit configured to process a radio-frequency signal and the radio-frequency module described above that is configured to communicate the radio-frequency signal between the signal processing circuit and an antenna.

The present disclosure can provide a small radio-frequency module and a small communication device that include a plurality of low-noise amplifiers with improved characteristics.

Other features, elements, characteristics, and advantages of the present disclosure will become more apparent from the following detailed description of preferred embodiments of the present disclosure with reference to the attached drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a circuit configuration diagram of a radio-frequency module and a communication device according to an embodiment;

FIG. **2** is a circuit configuration diagram of an integrated circuit (IC) device of the radio-frequency module according to the embodiment;

FIG. **3** is a sectional view of the radio-frequency module according to the embodiment;

FIG. **4** is a sectional view of a radio-frequency module according to a first modification of the embodiment;

FIG. **5** is a sectional view of a radio-frequency module according to a second modification of the embodiment; and

FIG. **6** is a sectional view of a radio-frequency module according to a third modification of the embodiment.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Hereinafter, a radio-frequency module and a communication device according to a preferred embodiment of the present disclosure will be described in detail with reference to the drawings. It should be noted that the embodiment described below is one specific example of the present disclosure. Consequently, for example, numerical values, shapes, materials, constituent elements, arrangements of the constituent elements, connection modes of the constituent elements, steps, and the order of the steps given in the following embodiment are mere examples and are not intended to limit the present disclosure. Among the constituent elements in the following embodiment, constituent elements not recited in any of the independent claims are described as arbitrary constituent elements.

The drawings are schematic drawings and are not always depicted in an exact manner. Thus, for example, the drawings are not consistent in terms of scale. Like reference symbols are used to denote substantially like configurations in the drawings, and redundant descriptions thereof are omitted or simplified.

In the circuit configuration of the present disclosure, the expression “directly coupled” denotes that a circuit element is directly coupled to another circuit element by using a connection terminal and/or a wiring conductor without intermediate connection with still another circuit element. By contrast, the expression “coupled” includes not only the case in which a circuit element is directly coupled to another circuit element by using a connection terminal and/or a wiring conductor but also the case in which a circuit element is electrically coupled to another circuit element via still another circuit element. The expression “coupled between A and B” denotes that a circuit element is coupling to both A and B while the circuit element is positioned between A and B.

With regard to the component arrangement of the present disclosure, the expression “when a substrate is viewed in plan view” denotes that objects orthogonally projected on a major surface of the substrate are viewed in a direction perpendicular to the major surface of the substrate. Additionally, the expression “A coincides with B when a substrate is viewed in plan view” denotes that at least a part of the region of A orthogonally projected on a major surface coincides with at least a part of the region of B orthogonally projected on the major surface.

Furthermore, the expression "a component is disposed at a substrate" includes the case in which the component is positioned in contact with the substrate, the case in which the component is positioned over the substrate without contact with the substrate (for example, the component is stacked on a component disposed on the substrate), and the case in which the component is partially or entirely embedded in the substrate. The expression "a component is disposed at a major surface of a substrate" includes the case in which the component is positioned in contact with the major surface of the substrate, the case in which the component is positioned over the major surface without contact with the major surface, and the case in which the component is partially embedded in the substrate at the major surface.

In this specification, words used to express relationships between elements, such as parallel and vertical, and numerical ranges do not necessarily denote the exact meanings but denote substantially the same meanings involving, for example, several percent differences.

Embodiment

1. Circuit Configuration of Radio-Frequency Module and Communication Device

Hereinafter, a circuit configuration of a radio-frequency module **1** and a communication device **5** according to the present embodiment will be described with reference to FIG. **1**. FIG. **1** is a circuit configuration diagram of the radio-frequency module **1** and the communication device **5** according to the present embodiment.

1-1. Circuit Configuration of Communication Device

Firstly, a circuit configuration of the communication device **5** will be described. As illustrated in FIG. **1**, the communication device **5** according to the present embodiment includes the radio-frequency module **1**, an antenna **2**, a radio-frequency integrated circuit (RFIC) **3**, and a baseband integrated circuit (BBIC) **4**. Hereinafter, the constituent elements of the communication device **5** will be described in order.

The radio-frequency module **1** communicates a radio-frequency signal between the antenna **2** and the RFIC **3**. The circuit configuration of the radio-frequency module **1** will be described later. The term "circuit", is used herein to be synonymous with "circuitry" (i.e., one or more circuits). Thus, when referencing RFIC **3**, is should be understood that RFIC **3** is circuitry that may include one or more separate circuits.

The antenna **2** is coupled to the antenna connection terminal **90** of the radio-frequency module **1**. The antenna **2** receives a radio-frequency signal from outside and outputs the radio-frequency signal to the radio-frequency module **1**.

The RFIC **3** is an example of a signal processing circuit for processing a radio-frequency signal. Specifically, the RFIC **3** processes a high-frequency receive signal inputted through a receive path of the radio-frequency module **1** by performing, for example, downconversion and outputs the processed receive signal generated by the signal processing to the BBIC **4**. In this context the term "high-frequency" is meant to refer to a signal between baseband and the RF channel frequency, and not necessarily the 3 MHz to 30 MHz "HF band". The RFIC **3** includes a controller for controlling, for example, a switch and a low-noise amplifier of the radio-frequency module **1**. The function of the controller of the RFIC **3** may be partially or entirely implemented outside the RFIC **3**; for example, the function of the controller may be partially or entirely implemented in the BBIC **4** or the radio-frequency module **1**.

The BBIC **4** is a baseband signal processing circuit configured to perform signal processing by using an intermediate frequency band lower than radio-frequency signals communicated by the radio-frequency module **1**. The BBIC **4** processes, for example, image signals used to display images and/or sound signals used for calls via a speaker.

In the communication device **5** according to the present embodiment, the antenna **2** and the BBIC **4** are non-essential constituent elements.

1-2. Circuit Configuration of Radio-Frequency Module

Next, a circuit configuration of the radio-frequency module **1** will be described. As illustrated in FIG. **1**, the radio-frequency module **1** includes low-noise amplifiers **21**, **22**, and **23**, switching circuits **51** and **52**, filters **61**, **62**, and **63**, matching networks (MNs) **71**, **72**, and **73**, the antenna connection terminal **90**, and a radio-frequency output terminal **91**. The radio-frequency module **1** includes an integrated circuit (IC) device **100**. The IC device **100** includes the plurality of low-noise amplifiers **21**, **22**, and **23**. Additionally, the radio-frequency module **1** includes an inductor L (refer to FIG. **2**) electrically coupled to the IC device **100**. The inductor L is not illustrated in FIG. **1**.

The antenna connection terminal **90** is an example of an external connection terminal. The antenna connection terminal **90** is coupled to the antenna **2**.

The radio-frequency output terminal **91** is an example of an external connection terminal. The radio-frequency output terminal **91** is configured to provide a radio-frequency signal outside the radio-frequency module **1**. The radio-frequency output terminal **91** is coupled to the RFIC **3**.

Each of the low-noise amplifiers **21**, **22**, and **23** is one of a plurality of low-noise amplifiers included in the IC device **100**. The low-noise amplifiers **21**, **22**, and **23** respectively amplify radio-frequency signals in communication bands A, B, and C. Radio-frequency signals in the communication bands are amplified by the corresponding low-noise amplifiers **21**, **22**, and **23** and outputted from the radio-frequency output terminal **91** via the switching circuit **52**.

The communication bands A, B, and C are frequency bands determined by standards organizations for communication systems developed by employing radio access technologies (RATs). The standards organizations include, for example, the 3rd Generation Partnership Project (3GPP) and the Institute of Electrical and Electronics Engineers (IEEE).

The communication bands A, B, and C are different from each other and used for an identical communication system or communication systems different from each other. For example, the communication bands A, B, and C are, but not limited to, a 5th Generation New Radio (5GNR) band, a Long Term Evolution (LTE) band, and a Wireless Local Area Network (WLAN) band.

A specific configuration of the low-noise amplifiers **21**, **22**, and **23** will be described later with reference to FIG. **2**.

Returning to FIG. **1**, the filter **61** is coupled between the antenna connection terminal **90** and the low-noise amplifier **21**. The filter **61** passes signals in the receive frequency range of a communication band A out of radio-frequency receive signals inputted from the antenna connection terminal **90**.

The filter **62** is coupled between the antenna connection terminal **90** and the low-noise amplifier **22**. The filter **62** passes signals in the receive frequency range of the communication band B out of radio-frequency receive signals inputted from the antenna connection terminal **90**.

The filter **63** is coupled between the antenna connection terminal **90** and the low-noise amplifier **23**. The filter **63** passes signals in the receive frequency range of the communication band C out of radio-frequency receive signals inputted from the antenna connection terminal **90**.

The matching network **71** is an input matching network for the low-noise amplifier **21**. The matching network **71** is coupled to an input terminal of the low-noise amplifier **21**. The matching network **71** is positioned between the filter **61** and the low-noise amplifier **21** and directly coupled to the filter **61** and the low-noise amplifier **21**. The matching network **71** performs impedance matching between the filter **61** and the low-noise amplifier **21**.

The matching network **72** is an input matching network for the low-noise amplifier **22**. The matching network **72** is coupled to an input terminal of the low-noise amplifier **22**. The matching network **72** is positioned between the filter **62** and the low-noise amplifier **22** and directly coupled to the filter **62** and the low-noise amplifier **22**. The matching network **72** performs impedance matching between the filter **62** and the low-noise amplifier **22**.

The matching network **73** is an input matching network for the low-noise amplifier **23**. The matching network **73** is coupled to an input terminal of the low-noise amplifier **23**. The matching network **73** is positioned between the filter **63** and the low-noise amplifier **23** and directly coupled to the filter **63** and the low-noise amplifier **23**. The matching network **73** performs impedance matching between the filter **63** and the low-noise amplifier **23**.

The switching circuit **51** is coupled between the antenna connection terminal **90** and the filters **61**, **62**, and **63**. Specifically, the switching circuit **51** includes terminals **511**, **512**, **513**, and **514**. The terminal **511** is a common terminal. The terminal **511** is coupled to the antenna connection terminal **90**. The terminals **512**, **513**, and **514** are selection terminals. The terminals **512**, **513**, and **514** are respectively coupled to the filters **61**, **62**, and **63**. In accordance with, for example, a control signal from the RFIC **3**, the switching circuit **51** can connect a corresponding one of the terminals **512**, **513**, and **514** to the terminal **511**. This means that the switching circuit **51** can control connection between the antenna **2** and the filter **61**, connection between the antenna **2** and the filter **62**, and connection between the antenna **2** and the filter **63**. The switching circuit **51** is implemented as, for example, a single-pole triple-throw (SP3T) switching circuit. The switching circuit **51** is referred to as an antenna switch.

The switching circuit **52** is coupled between the radio-frequency output terminal **91** and the low-noise amplifiers **21**, **22**, and **23**. Specifically, the switching circuit **52** includes terminals **521**, **522**, **523**, and **524**. The terminal **521** is a common terminal. The terminal **521** is coupled to the radio-frequency output terminal **91**. The terminals **522**, **523**, and **524** are selection terminals. The terminals **522**, **523**, and **524** are respectively coupled to an output terminal of the low-noise amplifier **21**, an output terminal of the low-noise amplifier **22**, and an output terminal of the low-noise amplifiers **23**. In accordance with, for example, a control signal from the RFIC **3**, the switching circuit **52** can connect a corresponding one of the terminals **522**, **523**, and **524** to the terminal **521**. This means that the switching circuit **52** can control connection between the RFIC **3** and the low-noise amplifier **21**, connection between the RFIC **3** and the low-noise amplifier **22**, and connection between the RFIC **3** and the low-noise amplifier **23**. The switching circuit **52** is implemented as, for example, an SP3T switching circuit. The switching circuit **52** is referred to as a band selection switch.

One or some of the circuit elements illustrated in FIG. **1** may be excluded from the radio-frequency module **1**. For example, the radio-frequency module **1** only needs to include at least the IC device **100** without the other circuit elements.

1-3. Circuit Configuration of IC Device

Next, a circuit configuration of the IC device **100** will be described with reference to FIG. **2**. FIG. **2** is a circuit configuration diagram of the IC device **100** according to the present embodiment.

As illustrated in FIG. **2**, the IC device **100** includes the low-noise amplifiers **21**, **22**, and **23**, inductors L**1** and L**2**, and a switching circuit **110**. The IC device **100** also includes a connection terminal **101**. The connection terminal **101** is an external connection terminal of the IC device **100**. The connection terminal **101** is grounded via the inductor L.

The low-noise amplifier **21** includes a transistor TR**1**. The transistor TR**1** is an amplifier transistor configured to amplify a radio-frequency signal (specifically, a radio-frequency signal in the communication band A) inputted to an input terminal In**1** and output the signal from an output terminal Out**1**.

The transistor TR**1** is, for example, a field effect transistor (FET). The gate of the transistor TR**1** is coupled to the input terminal In**1** of the low-noise amplifier **21**. The drain of the transistor TR**1** is coupled to the output terminal Out**1** of the low-noise amplifier **21**. The source of the transistor TR**1** is coupled to the inductor L**1**.

The low-noise amplifier **22** includes a transistor TR**2**. The transistor TR**2** is an amplifier transistor configured to amplify a radio-frequency signal (specifically, a radio-frequency signal in the communication band B) inputted to an input terminal In**2** and output the signal from an output terminal Out**2**.

The transistor TR**2** is, for example, a FET. The gate of the transistor TR**2** is coupled to the input terminal In**2** of the low-noise amplifier **22**. The drain of the transistor TR**2** is coupled to the output terminal Out**2** of the low-noise amplifier **22**. The source of the transistor TR**2** is coupled to the inductor L**2**.

The low-noise amplifier **23** includes a transistor TR**3**. The transistor TR**3** is an amplifier transistor configured to amplify a radio-frequency signal (specifically, a radio-frequency signal in the communication band C) inputted to an input terminal In**3** and output the signal from an output terminal Out**3**.

The transistor TR**3** is, for example, a FET. The gate of the transistor TR**3** is coupled to the input terminal In**3** of the low-noise amplifier **23**. The drain of the transistor TR**3** is coupled to the output terminal Out**3** of the low-noise amplifier **23**. The source of the transistor TR**3** is coupled to the switching circuit **110**.

The switching circuit **110** is coupled between the source of the transistor TR**1**, the source of the transistor TR**2**, and the source of the transistor TR**3**, and the connection terminal **101**. The switching circuit **110** includes terminals **111**, **112**,

113, and **114**. The terminal **111** is a common terminal. The terminal **111** is coupled to the connection terminal **101**. The terminals **112**, **113**, and **114** are selection terminals. The terminals **112**, **113**, and **114** are respectively coupled to the source of the transistor TR**1**, the source of the transistor TR**2**, and the source of the transistor TR**3**. Specifically, the terminal **112** is coupled to the source of the transistor TR**1** via the inductor L**1**. The terminal **113** is coupled to the source of the transistor TR**2** via the inductor L**2**. The terminal **114** is directly coupled to the source of the transistor TR**3**.

The switching circuit **110** controls connection between the source of the transistor TR**1** and the inductor L, connection between the source of the transistor TR**2** and the inductor L, and connection between the source of the transistor TR**3** and the inductor L. Specifically, in accordance with, for example, a control signal from the RFIC **3**, the switching circuit **110** can connect a corresponding one of the terminals **112**, **113**, and **114** to the terminal **111**. This means that the switching circuit **110** can control connection between the source of the transistor TR**1** and the inductor L, connection between the source of the transistor TR**2** and the inductor L, and connection between the source of the transistor TR**3** and the inductor L. The switching circuit **110** is implemented as, for example, an SP3T switching circuit.

The switching circuit **110** is controlled in conjunction with the switching circuits **51** and **52**. For example, when the antenna **2** receives a radio-frequency signal in the communication band A, the terminal **511** is coupled to the terminal **512** in the switching circuit **51**; the terminal **521** is coupled to the terminal **522** in the switching circuit **52**; and the terminal **111** is coupled to the terminal **112** in the switching circuit **110**. In this manner, the radio-frequency signal in the communication band A can be amplified by the low-noise amplifier **21**.

In the present embodiment, the source of the transistor TR**1**, the source of the transistor TR**2**, and the source of the transistor TR**3** are all configured to be grounded via the switching circuit **110**. For example, the terminal **111** is coupled to the terminal **112** in the switching circuit **110**, and as a result, the source of the transistor TR**1** is grounded via the inductors L**1** and L. The terminal **111** is coupled to the terminal **113** in the switching circuit **110**, and as a result, the source of the transistor TR**2** is grounded via the inductors L**2** and L. The terminal **111** is coupled to the terminal **114** in the switching circuit **110**, and as a result, the source of the transistor TR**3** is grounded via the inductor L.

The inductors L, L**1**, and L**2** each function as a part or all of the source inductor of a corresponding one of the transistors TR**1**, TR**2** and TR**3** included in the IC device **100**. The inductors L**1** and L**2** are provided in the IC device **100**. The inductor L is an example of an external inductor provided outside the IC device **100**. The inductor L is coupled between the connection terminal **101** and the ground. The inductor L is coupled in series with each of the inductors L**1** and L**2** via the switching circuit **110**.

The source inductor is coupled between the source of an amplifier transistor grounded via the source and the ground. The source inductor controls the impedance between the source of an amplifier transistor and the ground. The impedance is controlled to be an appropriate value, and thus, the amplifier transistor can appropriately amplify an input radio-frequency signal.

The inductance of the source inductor can be determined in accordance with the frequency of the radio-frequency signal inputted to the amplifier transistor. Specifically, when the frequency of the radio-frequency signal inputted to the amplifier transistor is relatively low, the inductance of the source inductor is increased.

In the present embodiment, the transistors TR**1**, TR**2** and TR**3** differ from each other in terms of the frequency of the radio-frequency signal inputted to each transistor. Thus, the transistors TR**1**, TR**2** and TR**3** also differ from each other with respect to the inductance of the source inductor. For example, it is assumed that the frequency of a radio-frequency signal in the communication band A inputted to the transistor TR**1** is the lowest and the frequency of a radio-frequency signal in the communication band C inputted to the transistor TR**1** is the highest. In this case, the inductance of the source inductor of the transistor TR**1** is the largest, and the inductance of the source inductor of the transistor TR**3** is the smallest.

In the present embodiment, the source inductor of the transistor TR**1** is constituted by the inductor L**1** in the IC device **100** and the inductor L outside the IC device **100** coupled in series with each other. The source inductor of the transistor TR**2** is constituted by the inductor L**2** in the IC device **100** and the inductor L outside the IC device **100** coupled in series with each other. The source inductor of the transistor TR**3** is constituted by only the inductor L outside the IC device **100**.

As described above, the external inductor L is shared by the transistors TR**1**, TR**2**, and TR**3**. The inductance of the inductor L is determined to be a value suitable for the source inductor of the transistor TR**3**. To provide compensation for insufficient inductance of the transistors TR**1** and TR**2**, the inductors L**1** and L**2** are individually provided in the IC device **100**.

The Q factor of the inductor L outside the IC device **100** is usually higher than the Q factor of the inductor L**1** and the Q factor of the inductor L**2** provided inside the IC device **100**. Using the inductor L with high Q factor and low loss enhances electrical characteristics of the low-noise amplifiers **21**, **22**, and **23**.

For example, the inductance of the inductor L is larger than both the inductance of the inductor L**1** and the inductance of the inductor L**2**. Since the inductance of the inductor L with high Q factor and low loss occupies as much inductance required for the source inductor as possible, electrical characteristics can be enhanced.

It should be noted that another inductor may also be coupled between the transistor TR**3** and the terminal **114**.

2. Component Arrangement of Radio-Frequency Module

Next, a component arrangement of the radio-frequency module **1** configured as described above will be described with reference to FIG. **3**.

FIG. **3** is a sectional view of the radio-frequency module **1** according to the present embodiment. As illustrated in FIG. **3**, the radio-frequency module **1** includes, in addition to the circuit components including the circuit elements illustrated in FIG. **1**, a chip inductor **120**, a module substrate **130**, resin members **140** and **141**, a plurality of post electrodes **150**, and a shield electrode layer **160**.

The module substrate **130** includes major surfaces **131** and **132**. The module substrate **130** may be, for example, a low temperature co-fired ceramics (LTCC) substrate having a layered structure composed of a plurality of dielectric layers, a high temperature co-fired ceramics (HTCC) substrate, a component-embedded substrate, a substrate including a redistribution layer (RDL), or a printed board, but the module substrate **130** is not limited to these examples.

The major surface **131** is an example of a first major surface. The major surface **131** may be referred to as an upper surface or front surface when appropriate. The switching circuit **51**, the filter **61**, the matching network **71**, and the chip inductor **120** are disposed at the major surface **131**. The switching circuit **52**, the filters **62** and **63**, and the matching networks **72** and **73** are also disposed at the major surface **131**, which are not illustrated in FIG. **3**.

The major surface **132** is an example of a second major surface that is opposite to the first major surface. The major surface **132** may be referred to as a lower surface or back surface when appropriate. The IC device **100** is disposed at the major surface **132**. The separation of the elements between the major surfaces **131** and **132** is a mere example, and the separation of the elements should not be construed in a limiting sense.

The IC device **100** is a component (semiconductor integrated circuit) including an electronic circuit formed on and inside a semiconductor chip (also referred to as a die). The IC device **100** is constituted by, for example, a complementary metal-oxide semiconductor (CMOS). Specifically, the IC device **100** is manufactured by a silicon on insulator (SOI) process. As a result, the IC device **100** can be inexpensively manufactured. The IC device **100** may be formed from at least one of GaAs, SiGe, and GaN. As a result, the IC device **100** can be manufactured with high quality.

The chip inductor **120** is an example of a first chip component including the inductor L illustrated in FIG. **2**.

In the present embodiment, the chip inductor **120** coincides with the IC device **100** when viewed in plan view. For example, as illustrated in FIG. **3**, the chip inductor **120** coincides with the inductor L**1** in the IC device **100** when viewed in plan view. The chip inductor **120** may coincide with the inductor L**2** instead of or together with the inductor L**1**.

The switching circuits **51** and **52** are implemented as semiconductor integrated circuits in the same manner as the IC device **100**. The IC device **100** may include the switching circuits **51** and **52**.

The filters **61**, **62**, and **63** are each implemented as, for example, a surface acoustic wave (SAW) filter, a bulk acoustic wave (BAW) filter, an LC resonance filter, or a dielectric filter, or any combination thereof, but the filters **61**, **62**, and **63** are not limited to these examples.

The matching networks **71**, **72**, and **73** are each implemented as, for example, a surface mount device (SMD) including an inductor and/or a capacitor. The surface mount device is an example of a second chip component including at least one of the matching networks **71**, **72**, and **73**.

The filters **61**, **62**, and **63** and the matching networks **71**, **72**, and **73** may be partially or entirely formed in the module substrate **130** and may be implemented as an integrated passive device (IPD).

A via-conductor **133** is provided at the module substrate **130**. The via-conductor **133** is a conductor filling a through via penetrating the module substrate **130** in a thickness direction. The via-conductor **133** electrically couples the connection terminal **101** (refer to FIG. **2**) of the IC device **100** and the chip inductor **120**.

The via-conductor **133** may be constituted by a conductor filling a blind via formed at the major surface **131**, a conductor filling a blind via formed at the major surface **132**, and a planer electrode pattern connecting the conductors filling the two blind vias in the module substrate **130**.

The resin member **140** is disposed on the major surface **131** of the module substrate **130** to cover the circuit components disposed at the major surface **131**. The resin member **141** is disposed on the major surface **132** of the module substrate **130** to cover the circuit components disposed at the major surface **132**. The resin members **140** and **141** make the circuit components reliable with respect to characteristics such as mechanical strength and moisture resistance.

The post electrodes **150** function as external connection terminals including the antenna connection terminal **90** and the radio-frequency output terminal **91**. The post electrodes **150** are disposed at the major surface **132** of the module substrate **130** to stand perpendicularly to the major surface **132**. The post electrodes **150** penetrate the resin member **141**, and one end of each post electrode **150** is exposed from the resin member **141**. The one end of each post electrode **150** exposed from the resin member **141** is coupled to, for example, one of input-output terminals and/or ground electrodes at a mother substrate disposed on the lower surface side with respect to the radio-frequency module **1**.

The shield electrode layer **160** is a metallic thin film formed by employing, for example, a sputtering technique. The shield electrode layer **160** covers upper and side surfaces of the resin member **140**, side surfaces of the module substrate **130**, and side surfaces of the resin member **141**. The shield electrode layer **160** is set at a ground potential, and as a result, the shield electrode layer **160** can prevent the entrance of foreign noises into the circuit components constituting the radio-frequency module **1**.

3. Effects

As described above, the radio-frequency module **1** according to the present embodiment includes the IC device **100** and the inductor L provided outside the IC device **100**. The IC device **100** includes the low-noise amplifiers **21**, **22**, and **23** each having an amplifier transistor, the inductors L**1** and L**2** respectively coupled to the emitter or source of the transistor TR**1** and the emitter or source of the transistor TR**2**, and the switching circuit **110** coupled between the emitter or source of the transistor TR**1**, the emitter or source of the transistor TR**2**, and the emitter or source of the transistor TR**3** and the inductor L. The inductor L is coupled between the switching circuit **110** and the ground in series with the inductors L**1** and L**2** via the switching circuit **110**.

The low-noise amplifiers **21**, **22**, and **23** are integrated together in this manner, and thus, the radio-frequency module **1** can be downsized. Additionally, since the source inductor of the transistor TR**1**, the source inductor of the transistor TR**2**, and the source inductor of the transistor TR**3** are partially or entirely implemented as the inductor L outside the IC device **100**, spaces necessary for the inductors L**1** and L**2** in the IC device **100** are reduced. As a result, the radio-frequency module **1** can be downsized.

Further, the Q factor of the inductor L provided outside the IC device **100** can be increased more easily than the Q factor of the inductor L formed in the IC device **100**. The increased Q factor of a part or all of the source inductor reduces losses, and consequently, it is possible to enhance electrical characteristics of the low-noise amplifiers **21**, **22**, and **23**.

The low-noise amplifiers **21**, **22**, and **23** support different communication bands to each properly amplify a radio-frequency signal in a corresponding communication band. As such, it is possible to implement the small radio-frequency module **1** including the low-noise amplifiers **21**, **22**, and **23** supporting multiple bands while achieving improved characteristics.

If the source inductor of the transistor TR**1**, the source inductor of the transistor TR**2**, and the source inductor of the transistor TR**3** are all provided outside the IC device **100**, characteristics of the low-noise amplifiers **21**, **22**, and **23** can be improved. However, in this case, the IC device **100** needs external connection terminals for the individual low-noise amplifiers, which hinders downsizing of the IC device **100**. The present embodiment can reduce external connection terminals because the IC device **100** includes the switching circuit **110**, and accordingly, it is possible to achieve downsizing.

Furthermore, for example, the inductance of the inductor L is larger than both the inductance of the inductor L**1** and the inductance of the inductor L**2**.

Hence, the inductance of the inductor L with high Q factor can occupy as much inductance required for the source inductor as possible, and thus, electrical characteristics can be enhanced.

Moreover, for example, the radio-frequency module **1** according to the present embodiment further includes the module substrate **130** having the major surface **131** and the major surface **132** opposite to the major surface **131** and also includes the chip components disposed at the major surface **131**. The IC device **100** is disposed at the major surface **132**. The chip inductor **120** as a chip component including the inductor L coincides with the IC device **100** when viewed in plan view.

As such, the inductor L is implemented as the chip inductor **120**, and thus, it is possible to increase the Q factor of the inductor L. Further, since the components included in the radio-frequency module **1** are disposed at both surfaces of the module substrate **130**, it is possible to decrease the area of the module substrate **130** in comparison to the case in which the components are disposed at only one surface, which achieves downsizing of the radio-frequency module **1**. Furthermore, the chip inductor **120** and the IC device **100** coincide with each other when viewed in plan view, and this structure shortens the interconnection length between the chip inductor **120** and the IC device **100**. As a result, it is possible to reduce wiring losses and mismatching losses due to variations in wirings, which enhances electrical characteristics of the radio-frequency module **1**.

Moreover, for example, the chip inductor **120** coincides with the inductor L**1** or L**2** in the IC device **100** when the module substrate **130** is viewed in plan view.

This structure can further shorten the interconnection length between the chip inductor **120** (the inductor L) and the inductor L**1** or L**2**. As a result, it is possible to further reduce wiring losses and mismatching losses due to variations in wirings, which further enhances electrical characteristics of the radio-frequency module **1**.

Further, for example, the communication device **5** according to the present embodiment includes the RFIC **3** configured to process a radio-frequency signal and the radio-frequency module **1** configured to communicate a radio-frequency signal between the RFIC **3** and the antenna **2**.

This configuration enables the communication device **5** to achieve almost the same effects as the effects of the radio-frequency module **1**.

4. Modifications

Hereinafter, modifications to the embodiment described above will be described.

4-1. First Modification

Firstly, a first modification will be described. This modification differs from the embodiment mainly in the positional relationship between the IC device and the input matching networks. The following description mainly focuses on differences from the embodiment and omits or simplifies descriptions about common points.

FIG. **4** is a sectional view of a radio-frequency module **1**A according to this modification. As illustrated in FIG. **4**, the chip component including the matching network **71** does not coincide with at least one inductor in the IC device **100** when viewed in plan view. Specifically, the matching network **71** does not coincide with both the inductors L**1** and L**2** in the IC device **100** when viewed in plan view. In the example illustrated in FIG. **4**, the matching network **71** does not coincide with the IC device **100** when viewed in plan view.

The chip components including the matching networks **72** and **73**, which are not illustrated in the drawing, do not necessarily coincide with at least one inductor in the IC device **100** when viewed in plan view.

As described above, the radio-frequency module **1**A according to this modification includes a chip component including one input matching network for one of the low-noise amplifiers **21**, **22**, and **23**. The chip component does not coincide with the inductor L**1** or L**2** in the IC device **100** when viewed in plan view.

This structure hinders electromagnetic field coupling between the matching networks **71**, **72**, and **73** and the inductors L**1** and L**2** in the IC device **100**, and thus, it is possible to enhance electrical characteristics of the radio-frequency module **1**A.

4-2. Second Modification

Next, a second modification will be described. This modification differs from the embodiment mainly in that a ground electrode pattern is provided between the IC device and the input matching networks. The following description mainly focuses on differences from the embodiment and omits or simplifies descriptions about common points.

FIG. **5** is a sectional view of a radio-frequency module **1**B according to this modification. As illustrated in FIG. **5**, the radio-frequency module **1**B includes a ground electrode pattern **134** provided at the module substrate **130**. The ground electrode pattern **134** is a planer electrode pattern provided inside the module substrate **130**. For example, side surfaces of the ground electrode pattern **134** are coupled to the shield electrode layer **160**, and as a result, the ground electrode pattern **134** is set at the ground potential.

As described above, the radio-frequency module **1**B according to this modification includes a chip component including one input matching network for one of the low-noise amplifiers **21**, **22**, and **23** and the ground electrode pattern **134** provided at the module substrate **130**. The chip component including the one input matching network coincides with the ground electrode pattern **134** when viewed in plan view.

Because the ground electrode pattern **134** is provided, this structure hinders electromagnetic field coupling between the matching networks **71**, **72**, and **73** and the inductors L**1** and L**2** in the IC device **100**. Thus, it is possible to enhance electrical characteristics of the radio-frequency module **1**B.

4-3. Third Modification

Next, a third modification will be described. This modification differs from the embodiment mainly in that the inductor provided outside the IC device is provided at the module substrate. The following description mainly focuses on differences from the embodiment and omits or simplifies descriptions about common points.

FIG. **6** is a sectional view of a radio-frequency module **1**C according to this modification. As illustrated in FIG. **6**, the radio-frequency module **1**C includes the inductor L implemented as a planer electrode pattern instead of the chip inductor **120**. The inductor L is formed of at least one of a metal wire such as a stripline or microstripline and a via-conductor.

As such, in the radio-frequency module **1**C according to this modification, the inductor L provided outside the IC device **100** is implemented as a structure other than the chip inductor **120**. This case also achieves almost the same effects as the effects of the radio-frequency module **1** according to the embodiment.

Others

While the radio-frequency module and the communication device according to the present disclosure has been described above by using the embodiment and its modifications, the present disclosure is not limited to the embodiment.

For example, the IC device **100** may include two, four, or more low-noise amplifiers. This means that the radio-frequency module **1** may be configured to receive and process radio-frequency signals in two, four, or more communication bands. The filters, input matching networks, and selection terminals of switches included in the radio-frequency module **1** may be, for example, identical in number to the low-noise amplifiers.

Further, for example, the inductance of the inductor L outside the IC device **100** is larger than both the inductance of the inductor L**1** and the inductance of the inductor L**2** in the IC device **100** in the embodiment, but this should not be construed in a limiting sense. The inductance of the external inductor L may be identical to or different from the inductance of the internal inductor L**1** or the inductance of the internal inductors L**2**.

Furthermore, the transistors TR**1**, TR**2** and TR**3** may be, for example, bipolar transistors. In this case, the gate, drain, and source of FET in the above description are replaced with the base, collector, and emitter of bipolar transistor. At least one inductor included in the IC device **100** is coupled to the emitter of a bipolar transistor functioning as an amplifier transistor.

Moreover, for example, the electronic components including the IC device **100** are disposed at both surfaces of the module substrate **130** in the embodiment, but this should not be construed in a limiting sense. All the electronic components included in the radio-frequency module **1** may be disposed at only one surface of the module substrate **130**.

Further, for example, the external connection terminals of the radio-frequency module **1** are implemented as the post electrodes **150** in the embodiment, but this should not be construed in a limiting sense. The external connection terminals may be implemented as bump electrodes.

Furthermore, for example, the communication device **5** is a receiver in the embodiment, but this should not be construed in a limiting sense. The communication device **5** may be, for example, a transceiver. In this case, the radio-frequency module **1** may include a transmit circuit including, for example, power amplifiers and transmit filters.

In addition, all forms obtained by making to the embodiment and modifications various changes that occur to those skilled in the art and all forms implemented as any combination of components and functions according to the embodiment and modifications without departing from the scope of the present disclosure are embraced within the present disclosure.

The present disclosure can be used as a radio-frequency module provided at the front-end for various communication devices such as a mobile phone.

While preferred embodiments of the disclosure have been described above, it is to be understood that variations and modifications will be apparent to those skilled in the art without departing from the scope and spirit of the disclosure. The scope of the disclosure, therefore, is to be determined solely by the following claims.

What is claimed is:

1. A radio-frequency module comprising:
an integrated circuit (IC) device; and
an external inductor provided outside the IC device, wherein
the IC device includes
  a plurality of low-noise amplifiers including a plurality of amplifier transistors in one-to-one correspondence,
  one or more inductors coupled to one or more of the plurality of amplifier transistors, each inductor being coupled to an emitter or source of a corresponding one of the plurality of amplifier transistors, and
  a switching circuit coupled between an emitter or source of each of the plurality of amplifier transistors and the external inductor, and
the external inductor is coupled between the switching circuit and ground in series with each of the one or more inductors via the switching circuit.

2. The radio-frequency module according to claim **1**, wherein
an inductance of the external inductor is greater than an inductance of any of the one or more inductors.

3. The radio-frequency module according to claim **2**, further comprising:
a module substrate including a first major surface and a second major surface that is on an opposite side of the module substrate than the first major surface; and
a first chip component disposed at the first major surface, wherein
the IC device is disposed at the second major surface,
the first chip component includes the external inductor, and
from a plan view of the module substrate, a footprint of the first chip component coincides with a footprint of the IC device.

4. The radio-frequency module according to claim **3**, wherein
from the plan view of the module substrate, the footprint of the first chip component coincides with the one or more inductors in the IC device.

5. The radio-frequency module according to claim **4**, further comprising:
a second chip component including an input matching network for one of the plurality of low-noise amplifiers, wherein
from the plan view of the module substrate, the footprint of the second chip component does not coincide with any of the one or more inductors in the IC device.

6. The radio-frequency module according to claim **4**, further comprising:

a second chip component including an input matching network for one of the plurality of low-noise amplifiers; and

a ground electrode pattern provided at the module substrate, wherein

from the plan view of the module substrate, the footprint of the second chip component coincides with the ground electrode pattern.

7. The radio-frequency module according to claim **3**, further comprising:

a second chip component including an input matching network for one of the plurality of low-noise amplifiers, wherein

from the plan view of the module substrate, the footprint of the second chip component does not coincide with any of the one or more inductors in the IC device.

8. The radio-frequency module according to claim **3**, further comprising:

a second chip component including an input matching network for one of the plurality of low-noise amplifiers; and

a ground electrode pattern provided at the module substrate, wherein

from the plan view of the module substrate, the footprint of the second chip component coincides with the ground electrode pattern.

9. The radio-frequency module according to claim **1**, further comprising:

a module substrate including a first major surface and a second major surface that is on an opposite side of the module substrate than the first major surface; and

a first chip component disposed at the first major surface, wherein

the IC device is disposed at the second major surface,

the first chip component includes the external inductor, and

from a plan view of the module substrate, a footprint of the first chip component coincides with a footprint of the IC device.

10. The radio-frequency module according to claim **9**, wherein

from the plan view of the module substrate, the footprint of the first chip component coincides with the one or more inductors in the IC device.

11. The radio-frequency module according to claim **10**, further comprising:

a second chip component including an input matching network for one of the plurality of low-noise amplifiers, wherein

from the plan view of the module substrate, the footprint of the second chip component does not coincide with any of the one or more inductors in the IC device.

12. The radio-frequency module according to claim **10**, further comprising:

a second chip component including an input matching network for one of the plurality of low-noise amplifiers; and

a ground electrode pattern provided at the module substrate, wherein

from the plan view of the module substrate, the footprint of the second chip component coincides with the ground electrode pattern.

13. The radio-frequency module according to claim **9**, further comprising:

a second chip component including an input matching network for one of the plurality of low-noise amplifiers, wherein

from the plan view of the module substrate, the footprint of the second chip component does not coincide with any of the one or more inductors in the IC device.

14. The radio-frequency module according to claim **9**, further comprising:

a second chip component including an input matching network for one of the plurality of low-noise amplifiers; and

a ground electrode pattern provided at the module substrate, wherein

from the plan view of the module substrate, the footprint of the second chip component coincides with the ground electrode pattern.

15. A communication device comprising:

a signal processing circuit configured to process a radio-frequency signal; and

a radio-frequency module configured to communicate the radio-frequency signal between the signal processing circuit and an antenna, the radio-frequency module including

an integrated circuit (IC) device, and

an external inductor provided outside the IC device, wherein

the IC device includes

a plurality of low-noise amplifiers including a plurality of amplifier transistors in one-to-one correspondence,

one or more inductors coupled to one or more of the plurality of amplifier transistors, each inductor being coupled to an emitter or source of a corresponding one of the plurality of amplifier transistors, and

a switching circuit coupled between an emitter or source of each of the plurality of amplifier transistors and the external inductor, and

the external inductor is coupled between the switching circuit and ground in series with each of the one or more inductors via the switching circuit.

16. The communication device of claim **15**, wherein

an inductance of the external inductor is greater than an inductance of any of the one or more inductors.

17. The communication device of claim **15**, wherein the radio-frequency module further comprising:

a module substrate including a first major surface and a second major surface that is on an opposite side of the module substrate than the first major surface; and

a first chip component disposed at the first major surface, wherein

the IC device is disposed at the second major surface,

the first chip component includes the external inductor, and

from a plan view of the module substrate, a footprint of the first chip component coincides with a footprint of the IC device.

18. The communication device of claim **17**, wherein

from the plan view of the module substrate, the footprint of the first chip component coincides with the one or more inductors in the IC device.

19. The communication device of claim **17**, wherein the radio-frequency module further comprising:

a second chip component including an input matching network for one of the plurality of low-noise amplifiers, wherein

from the plan view of the module substrate, the footprint of the second chip component does not coincide with any of the one or more inductors in the IC device.

20. The communication device of claim **17**, wherein the radio-frequency module further comprising:

a second chip component including an input matching network for one of the plurality of low-noise amplifiers; and

a ground electrode pattern provided at the module substrate, wherein

from the plan view of the module substrate, the footprint of the second chip component coincides with the ground electrode pattern.

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